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The codes of matter and their applications

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Abstract

The elements in the periodic table are the building blocks used to form substances with different compositions. Nevertheless, it is the properties of substances that are decisive for their existence and practical applications. Searching for new class of materials with exotic properties has always been challenging because of the complexity of both the theoretical and the experimental approaches developed so far. Here, we propose that the three ubiquitous and paramount attributes of all existing matter charge (Q), spin (S) or rotational motion, and linear motion (K) can be used to account for the formation of different types of matter/materials and their properties that have been or will be known to us. The three attributes or original codes can produce six primary codes which can further produce another sixty codes. The physical meanings represented by each code are unlocked. The table consisting of the 60 codes is introduced as the table of properties of codes of matter. We demonstrate that these codes can be used as building blocks to form new properties and new materials. Many new types of quasiparticles and new classes of materials with exotic properties of Q, S and K are predicted. Their possible experimental realizations are proposed. The possible applications of the codes of matter in other fields such as elementary particles, photonics and chemistry are briefly discussed. We know that there should be more new materials and new electronic, spin and photonic states to be discovered, but we do not know what they are. The codes of matter clearly reveal to us how many and what they are and how easily we can recognize what they are. Experimental and theoretical exploration for new forms of matter, new quasiparticles, or new electronic and spin states, or new states of photon or properties of light, as well as macroscopic entities with exotic properties represented by the codes of matter, is imminent.

Keywords

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The codes of matter and their applications

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Abstract The elements in the periodic table are the building blocks used to form substances with different compositions. Nevertheless, it is the properties of substances that are decisive for their existence and practical applications. Searching for new class of materials with exotic properties has always been challenging because of the complexity of both the theoretical and the experimental approaches developed so far. Here, we propose that the three ubiquitous and paramount attributes of all existing matter charge (Q), spin (S) or rotational motion, and linear motion (K) can be used to account for the formation of different types of matter/materials and their properties that have been or will be known to us. The three attributes or original codes can produce six primary codes which can further produce another sixty codes. The physical meanings represented by each code are unlocked. The table consisting of the 60 codes is introduced as the table of properties of codes of matter. We demonstrate that these codes can be used as building blocks to form new properties and new materials. Many new types of quasiparticles and new classes of materials with exotic properties of Q, S and K are predicted. Their possible experimental realizations are proposed. The possible applications of the codes of matter in other fields such as elementary particles, photonics and chemistry are briefly discussed. We know that there should be more new materials and new electronic, spin and photonic states to be discovered, but we do not know what they are. The codes of matter clearly reveal to us how many and what they are and how easily we can recognize what they are. Experimental and theoretical exploration for new forms of matter, new quasiparticles, or new electronic and spin states, or new states of photon or properties of light, as well as macroscopic entities with exotic properties represented by the codes of matter, is imminent.

Keywords New materials · New electronic state · New method · Materials design

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1 Introduction

Thanks to the existence of matter and its degrees of freedom, the codes of matter (including dark matter) and the attributes for their existence can be explored and unlocked. Elementary particles or matter particles form the elements in the periodic table, and they constitute all the matter in the universe and all the substances in our world. Each element in the periodic table can be used as a building block to form substances with different chemical compositions. The periodic table has guided the creation of new substances with unprecedented great success since its invention in the eighteenth century. Nevertheless, it is the characteristics or properties of matter that are most significant for us.

Despite the complexity of all the different forms of matter and their properties, some fundamental attributes or codes should exist with which all the different forms of matter are endowed. We have always been eager to explore the unknown properties of existing forms of matter without any boundaries. To do this, we need to determine what are the fundamental attributes or codes that are responsible for the existence of elementary particles and other forms of matter, as well as determining their properties.

Here, we propose three ubiquitous and paramount codes or attributes that are found in all the existing forms of matter—electric charge (Q), spin (S) or rotational motion, and linear motion (K), which can be used to account for the formation of all the forms of matter or entities and their properties that have been or will be known to us, based on the following principles. Due to the contrasting duality from the nature of negative and positive states for each attribute, these three ubiquitous attributes or original codes can produce six primary codes. One of the important conservation laws in the physics of the universe is charge conservation. The negative (−Q) and positive (+Q) charges in the universe are balanced. Microscopic and macroscopic objects have spins that are either clockwise (−S) (or spin down) or anticlockwise (+S) (or spin up), based on the right-hand rule. To allow the charges to function or to do work, freedom of linear motion in space (or momentum, K) has to be allowed, which can involve negative (−K) or positive directions (+K) in the one-dimensional (1D) case. Therefore, we now have three pairs of entities or six entities −Q, +Q, −K, +K, and −S, +S, as shown in Table 1. We denote them as the six primary codes, and they can determine all Q, K, and S states in all the building blocks of materials/matter or matter particles or quasiparticles that exist in reality. Simply by combining any two codes, these six primary codes can further produce another sixty codes as illustrated in Table 2. The 60 codes can account for all types of building blocks or various entities such as particles or quasiparticles or ions or atoms with different Q, S, and K states, and they have many significant implications and applications. Only 36 types of single entities or particles could be possible (Table S1 online), and many of them can find their corresponding counterparts in reality, whereas those codes or entities or particles unknown to us so far can be regarded as possible new particles or quasiparticles, and can guide and tempt us to explore their existence in reality. We demonstrate that these codes can be used as building blocks to form new physical states of matters or new materials. Therefore, the table consisting of the 60 primary codes is introduced as the table of properties of codes of matter. This is similar to the periodic table of elements, with the fundamental difference that the former provides direct guidance for the formation of matter/materials based on properties, whereas the latter yields compounds with little information on physical properties. By pairing the 60 codes (or using the 60 codes as building blocks), many new types of quasiparticles and new classes of materials with exotic properties of Q, S, and K are predicted. The physical meanings represented by each code in Table 2 are unlocked, and their possible experimental realizations are also proposed.

The principles of the codes of matter reveal that searching for new forms of matter/materials will never be exhausted. The codes of matter can also find great applications in searching for new microscopic and macroscopic systems, from elemental particles to macroscopic objects. Experimental and theoretical exploration for new forms of

Table 1 Six primary codes: Q, K, and S

Charge		Freedom of linear motion		Spin or rotational motion	
1	2	3	4	or 5	or 6
−Q	+Q	−K	+K	−S	+S

Table 2 Properties of the codes of matter produced by Q, K and S

	I					II										III				
	K=0					-K or +K										-K and + K				
	S=0	S≠0		Mono-pole		S=0		S≠0				Mono-pole				S=0	S≠0		Mono-pole	
						-K	+K	-K		+K		-K	+K	-K	+K					
-Q	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
+Q	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
Q=0	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60

All the codes can be massless or massive. For massless case, each code should be replaced by an open circle matter, new quasiparticles, new electronic and spin states, or new states of photon or properties of light, as well as macroscopic entities with exotic properties represented by the codes of matter, is imminent. The codes of matter and the new periodic table of properties of the codes of matter offer a new alternative and simple platform and principles for scientific research. They can guide the design of new properties, materials, and devices, and have great potential applications in other fields where using conventional approaches to conduct breakthrough research has been exhausted.

We know that there should be more new materials/matter and new Q, S, and K states to be discovered, but we do not know what they are and how many they are. The codes of matter clearly reveal what they are and how many they are.

Mathematically, the six primary codes (Table 1) can result in 6! pairs of codes. After taking the duplications into account, however, the six primary codes can produce only 60 codes for single particles/entities with or without Q, S and K (Table 2).

The 60 codes can be divided into three groups of codes: group I represents (localized) entities or particles without K; group II represents free particles with −K or +K; group III represents particles with both −K and +K. Removing the duplications, we have only up to 36 codes in total for particles/entities that could exist in reality (Table S1 online). Many of them represent particles that actually exist, while those entities/particles unknown to us so far can be regarded as possible new particles/quasiparticles and can guide and tempt us to explore further. Furthermore, using the 60 codes (Table 2) as building blocks, many new types of new quasiparticles and new classes of materials with exotic properties of Q, S, and K can be predicted or formed.

Note that for convenience in discussion, our analyses of the codes in the present work are based on 1D direction for both K and S. All the codes can be easily extended to the two- and three-dimensional (2D or 3D) cases. In the following sections, we will demonstrate how to use these 60 codes (Table 2) as building blocks to form new types of matter or new physical states of matter. This is similar to using the elements in the periodic table of elements to form compounds, with the fundamental difference that the former directly guides the formation of Q, K, and/or S states in materials/matter, while the latter yields matter/compounds with little information on physical properties.

Thanks to the Higgs field, mass is a universal attribute in all the matter/materials. The 60 codes produced from Q, K, and S could present any entities with or without (or light weight) mass which are represented by closed or open circles, respectively. The massless codes are very important and useful when they are used for the discussions related to any entities or particles which are massless such as massless Dirac fermions or light weight macroscopic objects.

2 Codes for single particles

2.1 Codes for existing particles

These 36 particles/codes (Table S1 online) have many interesting physical meanings. Many of the codes in group I can find their representative counterparts in existing particles that have been experimentally verified or theoretically proposed so far. Localized negatively or positively charged particles and charge neutral particles without K, are represented by the codes 1, 2, 13, 14, 25, and 26 in Table S1 (online). Their free counterparts are represented by the codes 5, 6, 17, 18, 29, and 30 in Table S1 (online). The oscillating motion of negative, positive, or charge neutral particles are represented by the codes 9, 10, 21, 22, 33, and 34 in Table S1 (online). They correspond to the directional and alternating motion of charged or charge neutral carriers in charge neutral or charged gas or liquids, or electrons or holes in conductive materials.

2.2 Codes for existing quasiparticles

There are many quasiparticles that have been observed or proposed experimentally or theoretically so far. Despite their variety and complexity, all of them can be simply assigned to some of the codes in Table S1 (online). Some of the remaining codes can represent new types of quasiparticles. The charge neutral codes can also be regarded as photons or magnons or neutrons, which have no charge, but have spin, as represented by the codes 30 or 34 in Table S1 (online), with spin for the photon and magnetic spin for the magnon. Quasiparticles such as holons and spinons [1] which only have charge without spin or spin without charge are represented by the codes 5, 17, 9, and 21, or 30 and 34 in Table S1 (online), respectively. As for code 25 in Table S1 (online), which has null charge and spin, it can represent a charge neutral atom or a particle without spin and charge in reality. For the massless code 26 in Table S1 (online), it could represent Majorona fermion [2]. The codes 29 and 33 in Table S1 (online) with no spin and charge, but having energy could represent the Higgs quasiparticles.

2.3 Codes for new particles

New particles with new K and S states which have been unknown to us so far are represented by some of the codes in Table S1 (online). For example, the codes, 3, 4, 15, 16, 27, and 28 in Table S1 (online) show both up and down spin on a single particle, indicating a unipolar particle. This resembles the magnetic monopole with either an "N" or "S" unipole [3–5]. Furthermore, the "monopole" can be localized (codes 3, 4, 15, 16, 27, 28 in Table S1 (online)) or delocalized (codes 7, 8, 19, 20, 31, 32, or codes 11, 12, 23, 24, 35, 36 in Table S1 (online)) with or without −Q or +Q. Obviously, it is not possible to have a "magnetic" monopole in reality for charged particles so far, although the "monopole"-charged codes can represent the weird case of a charged entity. It should be noted that any new single particles to be discovered in the future should be found or represented within the 36 codes. The codes 5, 6, 17, 18, 29, and 30 in Table S1 (online) could represent examples of a new type of quasiparticles or entities which can be called unidirectional particles. Graviton seems to be one of the candidates, as gravity is one-directional field. The codes may also direct us to possible new elemental particles (see sections below for details).

3 Matter or codes formed by pairing of codes

As parity is a very common phenomenon that exists in reality due to the attraction between particles having opposite charges or spin, we now use the 60 codes in Table 2 to form more pairs, with the aim of forming new entities/particles consisting of a pair of single particles or quasiparticles, and unlock their underlying abundant physical meanings for each new paired codes. We will also discuss their counterpart materials in reality when they are used as building blocks to compose real materials.

We take into account the following general criteria for the likelihood of pairing in reality: (1) particles with the same sign of charge tend to repel each other. So, they are unlikely to form pairs in reality; (2) on the other hand, the particles with opposite signs of charge are likely to be paired due to the force of attraction between them; (3) charged particles may attract neutral entities or particles due to polarization effect; (4) monopoles can attract or repel each other if they have the opposite or the same signs, respectively; (5) particles with spin can attract both types of monopole. Many codes of these pairs can find their counterparts in reality, and those unknown so far can be regarded as possible new quasiparticles. What is more exciting is that we can predict new materials using the pairs or codes of pairs as building blocks. Let us discuss them group by group (Table S2 online).

3.1 Existing materials from localized pairs

A few typical codes that find counterparts in reality are given in the first row in Table S3 (online). A pair of "+" and "−" charges with or without the same spin or opposite spin are commonly observed in ionic compounds and ionic ferromagnetic or antiferromagnetic materials. One can use the pairs as building blocks to compose 1D, 2D, or 3D nonmagnetic or ferromagnetic or antiferromagnetic compounds. The cases (in row A) d, e, and f in Table S3 (online) represent what are seen in existing ferromagnetic or antiferromagnetic compounds in which the constituent atoms are zero valence atoms such as transition metals and rare-earth-based magnetic metallic systems. The materials formed by pair c in Table S3 (online) have ferromagnetic (Fig. S1a online) or antiferromagnetic states, which have been seen in transition metal or rare-earth-metal-oxide materials in which the negative ions carry no spin. The codes a and b (row A) in Table S3 (online) represent matter/materials formed by ionic and covalent (or metallic) bonds, respectively. The electrically polar systems (such as ferroelectric systems) are represented by the case a in Table S3 (online), while the electrically polar state coexisting with magnetic state (such as ferroelectric magnets) is represented by the case of c in Table S3 (online), respectively.

3.2 Possible new materials from charged codes/pairs

The pairs (row B in Table S3 online) having a charged and non-charged particle, with or without parallel or antiparallel spin, respectively, are rarely seen in any existing materials. The materials made of these pairs may not be energetically stable due to nonzero net charges. As it is a mathematically predicted possibility, however, it inspires us to think about how this could be possible in reality. The pairs which violate charge conservation can be realized by the charging effect in insulating systems. This is very likely at least for the codes a, g, and k (row B) in Table S3 (online). It would be interesting to experimentally observe magnetism induced by the charging effect inside or at the surface/interface of charged magnetic systems (Fig. S1b online). The codes of h–j in Table S3 (online) with spin on negative charge directs to novel systems having magnetic moment from negative ions. This seems to be highly possible as we have seen magnetism in solid oxygen.

3.3 Paired codes for magnetic monopoles

Interestingly, the six primary codes can produce codes representing magnetic monopoles with different signs of the unipole, Q or K. For example, the codes 44 and 45 in Table 2 represent "N" and "S" type monopoles, respectively. It seems that the magnetic monopole combined with other particles may produce exotic states which imply that both magnetic dipoles can coexist in a system. One of the examples in reality could be a magnetically frustrated system, which can host monopoles [4]. The charged monopole pair may be a good guide in our search for the existence of monopoles in an electrically charged magnetic or non-magnetic system.

4 Codes of pairs with freedom of linear motion only

4.1 Existing quasiparticles or entities

The group of codes or pairs that only has freedom of linear motion represents the motion of particles either in the opposite or in the same direction (Table S4 online). Others, however, having different or opposite Q, K, and S, represent exotic combinations and have interesting physical meanings. The cases a and b in Fig. S2 (online) are commonly seen in two-atom molecular gases or liquids, and in some metallic solids. A charged particle can travel with a charge neutral particle due to electrical effects. Excitons or electron–hole pairs are represented by the code b in Fig. S2 (online).

It should be noted that pairs having the same charge sign but with motion in opposite directions seem unlikely to exist in reality, as they repel each other and move away each other. They can also be regarded as moving toward each other; however, these codes correspond to the electron collision process or to electron and positron annihilation which produces photons. In other words, the photon (a charge neutral code) can be produced either through the combination of "+" and "−" charges or by the motion of free charged particles, such as are represented by the codes c or f in Fig. S2 (online), which show a moving charged particle going in the same or opposite direction with a charge neutral particle.

4.2 Exotic or new electronic states and materials

We now look at this group of codes from a different angle. The representations of freedom of linear motion can be regarded as representing electronic states that resemble what is seen in charge carriers and momentum for conduction bands in electronic band structures in condensed matter. Therefore, we only need to discuss the nine codes with opposite signs of K, as shown in Fig. 1. We now demonstrate how to construct new types of band structures using these codes. After the construction, close circles may have to be removed in order to represent bands strictly for some cases.

We now have positive and negative momentum for two particles at the same level. These resemble the electronic states at the Fermi level (E_f) in conduction bands in electronic band structures for 1D case (Fig. 2). Case a (code 5 in Fig. 1) or b (code 1 in Fig. 1) in Fig. 2 refers to electron or hole-like charge carriers at the Fermi level, respectively. The code 9 in Fig. 1 is interesting, as it means charge neutral particles with opposite momentum. This code can well represent the

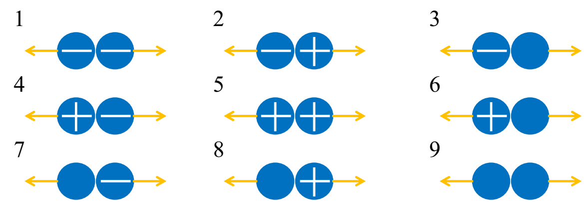


Fig. 1 Codes with K in opposite directions

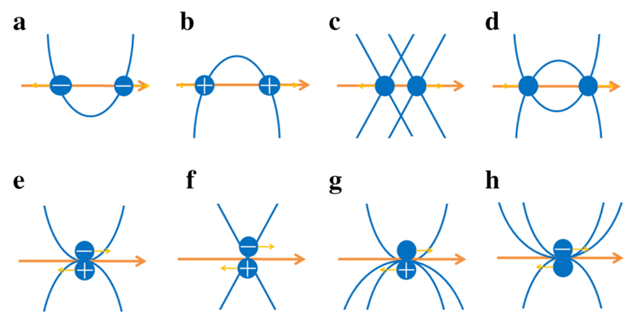


Fig. 2 Representative band structures of the codes in Fig. 1. The energy and moment dispersion can be linear (massless case) or parabolic or dspersionless or flat

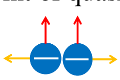
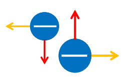
special case of a semimetal which has the same concentrations of electrons and holes as represented by the case c in Fig. 2 with linear dispersion or d in Fig. 2 with parabolic dispersion. This type of semimetal (here, we denote it as an electron–hole compensated semimetal or Dirac electron–hole compensated semimetal for parabolic or linear E–K dispersion, respectively) is highly possible in real materials, and we expect it to give a perfect electron–hole resonance effect and exotic magnetoelectronic states, such as the extremely large magnetoresistance observed in WTe_2 with compensated electrons and holes [6].

The remaining codes in Fig. 1, however, show strange features. The codes 2 and 4 in Fig. 1 show strange states: the electron has −K, while the hole has +K or vice versa. This is very unusual and has not been seen in any existing electronic materials. This is also true for codes 3, 6–8 in Fig. 1, where the hole or electron has +K, while the charge is neutral for −K or +K. One of the possible materials for realization of the strange states is zero-gap materials or gapless materials [7, 8]. The code 2 or 4 in Fig. 1 is possible when the conduction and valence bands touch at the Fermi level (e or f in Fig. 2). On the other hand, the band structure of possible materials having the codes 6 and 7 in Fig. 1 are represented by the band structures g and h in Fig. 2, respectively, which shows two valence (conduction) bands and one conduction (valence) band touching at the Fermi level. In addition, the energy dispersion for the cases can be either Dirac-like or parabolic [8]. All the nine codes also represent electronic states for flat bands or dispersionless bands. More exotic electronic states such as charge compensated or charge uncompensated states of the flat band and other states are expected and these will be further discussed in further study.

5 Codes of pairs with both K and S

There are 12 codes for pairs with both S and K (Table 2). The physical meanings of these paired codes share the same features as the pairs produced by codes with freedom of linear motion. Furthermore, this group of paired codes exhibit abundant interesting physical phenomena as the addition of the spin to the codes gives rise to more features. Materials possessing the features represented by many of the codes have been seen in existing spin-containing conductors/materials. Many codes show unusual electronic and spin features, however, which can inspire the search for new counterpart materials in reality.

5.1 Codes representing novel and existing materials

The pairs with opposite K can resemble the electronic states in band structures. They can also be discussed from viewpoint of quasiparticles. It is straightforward to link the code 1  or 4  (Fig. 3) to spin-triplet or spin-singlet Cooper pairs, respectively. One can imagine that the remaining codes can also represent many "new" quasiparticles, which require both theoretical and experimental exploration to determine their existence in reality.

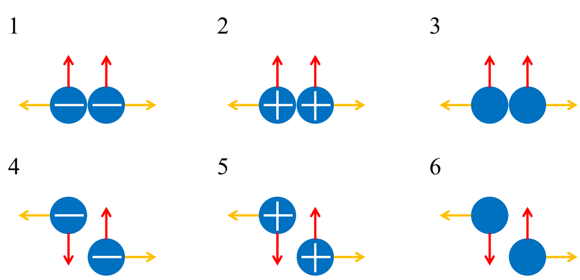
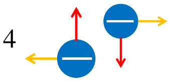
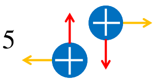
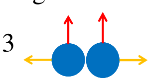
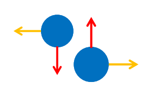


Fig. 3 A few typical codes with opposite K and same sign of charge, selected from Table S5 (online)

We now discuss six typical codes (Fig. 3) having charges with the same sign or neutral charges from the viewpoint of electronic conduction bands. The codes 1 and 2 in Fig. 3 represent the spin-polarized electrons typically seen in existing half-metals [9]. The codes 4  and 5  in Fig. 3 can also well represent the n- or p-type topological surface states in topological insulators, respectively [10–12]. Figure 4 shows their representative corresponding band structures for all these codes (Fig. 3). The code 3  in Fig. 3 represents a new class of materials which exhibit the semimetal state with equal electron and hole concentrations, but with full spin polarization. Note that the energy dispersion in Fig. 4 could be either linear or parabolic for massless or massive quasiparticles. Here, we denote this new class of materials as spin semimetals for parabolic dispersion or Dirac spin (e-h compensated) semimetal for linear dispersion, which resemble the spin gapless semiconductors with either parabolic or linear E–K dispersion (or Dirac spin gapless semiconductors) [13]. We can also have exotic states such as very heavy electrons and holes with full spin polarizations or electron–hole-compensated semimetals with full spin polarization, namely, spin flat band massive electrons or holes or spin massive (electron–hole-compensated) semimetals.

It is interesting to note that the code 6  (Fig. 3) could represent the charge neutral state with time-reversal symmetry, leading to another new class of materials. We can name it as topological electron–hole-

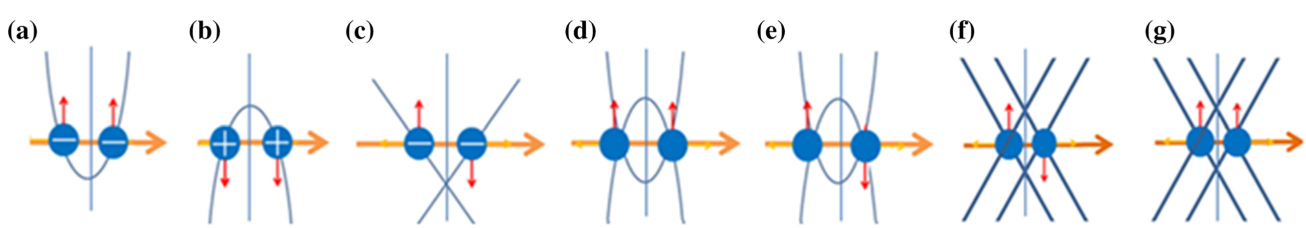


Fig. 4 Representative electronic conduction bands of a few typical codes from Fig. 3. The E-K dispersion can be linear or parabolic or dispersionless or flat. **a**, **b** Half-metals, **c** topological surface state, **d** spin (polarized) electron–hole-compensated semimetal, **e** topological electron–hole-compensated semimetal, **f** Dirac topological electron–hole-compensated semimetal, **g** Dirac spin (electron–hole-compensated) semimetal

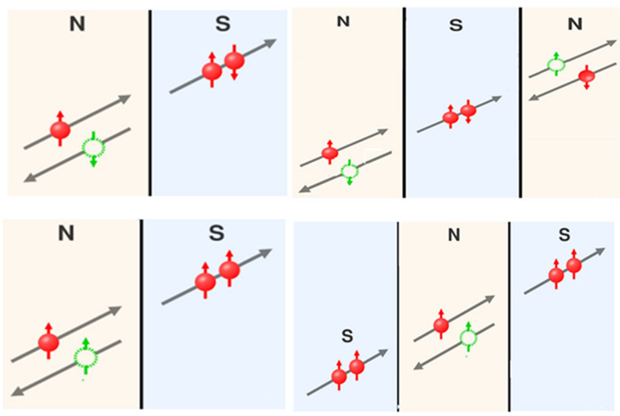
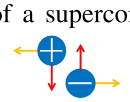
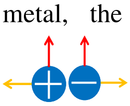
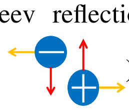
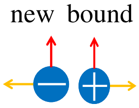


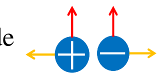
Fig. 5 Experimental realizations of several new quasiparticles or codes in Table S7 (online). The closed circles or open circles represent electrons or holes, respectively

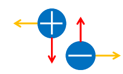
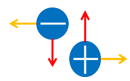
compensated semimetals. It can also represent a quasiparticle which is both chargeless and spinless.

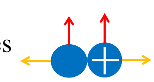
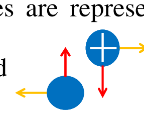
We now discuss the physical meanings for the codes paired by opposite charges or one with charge and the other one without charge, as shown in Table S6 (online). These codes indicate unusual electronic states which are not seen in any types of existing electronic band structures, inspiring us to design new class of materials with the strange electronic state. Such types of codes are given in Table S7 (online) as typical examples.

Thanks to the interface of a superconductor (S) and a normal metal (N), the code  can represent the electron and hole state in the Andreev reflection [14] at the interface of a triplet superconductor and a normal metal (Fig. 5, upper left). Inspired by the Andreev effect, using the interface of a singlet superconductor and a normal metal, the electronic state represented by the code  might be possible (Fig. 5, lower left). The crosstalk Andreev reflection [15] effect (Fig. 5, upper right) (the code ) can inspire us to produce new states or quasiparticles at the interface of normal metal and singlet superconductors.

The new bound state quasiparticle represented by the code 4  could be possibly realized by the S/N/S sandwich structure where the Andreev bound-state is formed when the S is a singlet superconductor (Fig. 5, lower right).

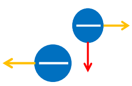
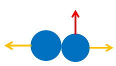
Another experimental realization for these codes could be possible based on spin gapless semiconductors having extremely narrow or zero band gaps (i.e., very finite charge carriers). The code  (Table S7 online) in the spin gapless state (where both the conduction and the valence band are fully spin-polarized with the same polarization and tiny overlap at the Fermi level) can occur under application of an electric field. All positive charges move along +K, and the negative ones along −K. An anomalous Hall effect with the same sign of spin accumulation is expected for magnetic field perpendicular to the electric field. Spin gapless semiconductors with spin up in the conduction band and spin down in the valence band are the platform for the electronic state represented by the code 1 or 3 in Table S7 (online). Under magnetic and electric fields, spin-up holes and spin-down electrons will accumulate at sample edges.

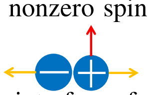
It should be pointed out that the code  or  also represents the bound state at the interface of a superconductor and a topological insulator or Rashba system [16, 17] with strong spin orbital coupling. As is well known, the bound state with zero mode represents a Majorana particle (fermion) in solid matter. So, the single-charge neutral code state can be realized by superposition of one negative and one positive charge codes with same or opposite spin direction. Therefore, spin gapless semiconductors can also serve as a platform for such a state when they hybridize with superconductors.

More unusual states are represented by codes such as codes  and  for quasiparticles with fractional charge. They can be made possible in spin gapless semiconductors, as shown in Fig. S3 (online). There should be two valence bands and one conduction band of the same sign, with one of the valence bands having the same charge density as the conduction band, making the electron–hole density equal at the Fermi level for the code 6. Possible band structure realizations for other codes are shown in Fig. S3 (online).

New quasiparticles or bound states stemming from these special codes might also be possible by taking advantage of interfaces formed with singlet or triplet superconductors when the electron or hole and charged or chargeless/neutral particles are in superposition.

5.2 Codes of pairs with K and S

The codes of pairs having one particle with K without S and the other with both K and S represent a very unusual electron state, as one particle has spin degeneracy and other one's spin degeneracy is lifted (Table S8 online). So far, none of the existing quasiparticles can be related to any of the codes. The stranger the codes, the better the chance we are given to explore new particles or new materials. If we regard this group of codes the same as the codes of pairs with K only, except that one of the particles has a spin, similar discussions to those on the meanings and experimental realizations in previous sections can be used. There are only five representative codes (Table S9 online) from the 36 codes in Table S10 (online). The pairs having the same sign of charge can be regarded as states that are seen in ferromagnetic conductors with partial spin polarization. Nevertheless, the spin is only present with either −K or +K, which is weird. Superposition of appropriate band structures could be one of the solutions for the realization of the codes. The superposition of the band structures of a spin gapless semiconductor and a topological insulator can produce a new band structure which shows a spinless electron for −K and a spin-polarized electron for +K. It is not clear, however, whether or not the state of code  can be experimentally realized (Fig. S4a online). The code  might be possible by using the superconducting proximity effect. The code will then represent a new weird quasiparticle which is its own antiparticle, but has nonzero spin (Fig. S4b online).

The code  and other such codes might be possible at the interface of a superconductor via an approach similar to those for the Andreev or crosstalk Andreev effect. The spin gapless semiconductor can also be the platform to produce these code states, as the zero-gap state can superimpose the particles at one k point (Fig. 6).

6 Codes of monopoles

The pairs consisting of monopoles have many possible combinations. They have the same states as for pairs with both spin and freedom of motion. If the monopole and pairs could exist in reality, they would exhibit similar features to those that we have discussed for pairs with Q, S and K. We can revisit all the possibilities if the free monopole particles could be found to exist in reality in the future.

7 Codes for pairs with freedom of linear motion in alternating directions

The codes in group III in Table S1 (online) represent particles simultaneously having motion in opposite directions. One can immediately think of the alternating motion of particles with or without the three attributes. In reality, codes 9, 10, 21, 22, 33, and 34 in Table S1 (online) represent a moving single particle/entity with or without

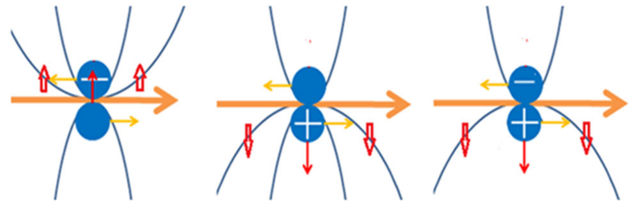
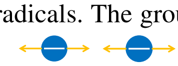
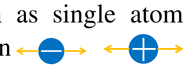
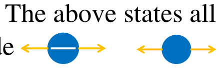
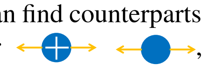


Fig. 6 Band structure realization of codes in Table S9 (online) via spin gapless semiconductors. The energy dispersion can be either linear (massless case), parobolic or dispersionless or flat

charge, spin, and freedom of motion in an alternating electric or magnetic field, which can be commonly seen in many existing materials, in charged or non-charged systems, with or without spins. The magnetic monopole can also be alternating. As to the paired alternating states, the discussion on which correspond to existing materials and which are unusual hypothetical materials or states should be similar to what has been analyzed for the codes of pairs with K only, simply by changing all the codes to alternating modes. Alternating motion of monopoles is represented by the codes in Table S11 (online).

This group of codes (Table S11 online) represents alternating motion (along the −K and +K directions) for charged or non-charged particles or radicals. The group of particles consisting of the code  …or code  has negative or positive charges moving in conductive matter under excitation of ac electric or magnetic fields, whereas code  can refer to random motion of charge mutual particles such as single atom molecules in the gaseous state. The code can  indicate excitons under ac excitation in solid matter. It can also mean the plasmonic charged state. The above states all can find counterparts in reality. The code  or , however, represents a nonzero net charged state with alternating charged and uncharged particles. This seems to be rarely seen in reality. Such a state can be realized in liquid conductive interfaces of positively or negatively charged electrodes under ac electric field.

The codes in Table S12 (online) show the pairs of particles having both motion in alternating directions and spin. As for the pairs consisting of monopoles, they may also have a possible representation resembling that of the electronic band structure. Nevertheless, a great challenge remains as to how monopole information can be included in the band structure (Table S13 online).

8 Applications of the codes of matter

8.1 Applications of the codes in materials science

As discussed previously, the codes for single entities or pairs can be used as building blocks to form matter/materials in reality. One of the primary applications of the codes of matter proposed here serves for this purpose. We can use any group of codes to form simple and complicated systems or materials. Obviously, the numbers of combinations using these codes are countless mathematically. Due to the restriction to only three attributes, however, the meaningful combinations may not exceed the mathematical calculation. The following are the potential applications of the codes of matter: (1) Both single codes or paired codes can be used to represent known particles and their charge and spin states which are known to us so far; (2) both types of codes can be used as building blocks for forming materials in reality; (3) new particles or quasiparticles, or electronic or spin states which are unknown to us can be predicted; (4) new classes of materials with unusual spin, charge, or freedom of motion in space can be predicted and developed. These have been discussed in the above sections.

Furthermore, Table 2 can be regarded as a "periodic" table of properties of codes of matter or entities. A "property" formula consisting of the three entities is proposed, which resembles a formula based on the periodic table of elements that is used to form a compound with a certain chemical composition formula. This will be discussed in detail in the following sections.

8.2 Applications for elementary particles

The codes may find useful applications in other particle systems, from elementary particles, to macroscopic particles/objects, to even cosmic celestial bodies. We briefly discuss how the codes are useful for predicting new elementary particles. In particle physics [18, 19], 17 elementary particles have been discovered experimentally. They are categorized into different groups based on charge, spin, and mass or energy, such as the fermions (quarks, leptons, antiquarks, and antileptons), which generally are "matter particles" and "antimatter particles", as well as the fundamental bosons (gauge bosons and Higgs boson), which generally are "force particles" that mediate interactions among fermions. The codes in the second row of Table 2 or Table S1 (online) can be regarded as the antiparticles of that in the first row, while, the codes in the third row represent particles being their own antiparticles. According to the codes in Table S1 (online), all the 17 particles can be represented by only five of the 36 particle codes with the code representing the W boson and three quarks having negative charge, spin, and mass, while code represents positively charged quarks and leptons, the code represents charge neutral leptons and bosons, code or represents massive massless and chargeless bosons, and the code represents the Higgs particle, which is spinless and chargeless (Fig. S5 online). The remaining 27 codes could represent or predict new elementary particles. The Table S1 (online) is reproduced as Table S14 (online) in order to clearly illustrate existing elemental particles associating with codes in Table S1 (online). The codes 1 and 13 in Table S1 (online) may indicate massless and spinless charged particles, the codes 2 and 14 in Table S1 (online) represent particles with spin and charge, while the codes 5, 9, 17, 21 (6, 10, 18, 22) in Table S1 (online) represent charged particles that are spinless (have spin); the codes 29 (30) and 33 (34) in Table S1 (online) are for particles that are chargeless without (with) spin. Code 25 in Table S1 (online) represents a particle that has no Q, S, and K which may direct to a new massive or massless particle. Code 26 in Table S1 (online) indicates a new massive or massless particle with spin but no charge and moment.

It is interesting to note that the codes 5, 17, and 29 in Table S1 (online) represent free particles that have a fixed momentum direction. They can be denoted as unidirectional particle, distinguishing them from the other free particles that have freedom of motion in both directions. This inspires us to propose strange particles that can only move along one direction in space. All the existing fields and their representative quasiparticles could be reversed with field reversion. The gravity field seems to be the only field having one direction without any reversion. Therefore, the codes 29 or 30 in Table S1 (online) could refer to a particle associated with gravity. The codes 5, 6, 17, and 18 in Table S1 (online) predict four new unidirectional particles with or without spin. Similarly, as time or space expansion proceeds along one direction, the code can also represent a time- or space-associated directional quasiparticle since time–space is a field too.

8.3 Possible applications in dark matter particles

In Table 2, the charge neutral code 41 is created by paring the codes 1 and 21, which gives rise to two consequences for the code 41: the code 41 has or has no charge components. A photon has no net electrical charge and spin, but it has both electric and magnetic components and behaves like a wave having both alternating electric and magnetic components. The so-called annihilation of an electron and a positron creates gamma ray photons. The negative and positive charges as well as their spins of the electron and positron in particle nature are transformed to an electromagnetic wave and carried by photons which have no net electric charge and magnetic (spin) moments. Both charge and spin components do not disappear, but are carried on their wave state instead. However, the code 41 in Table 2 can have no charge and magnetic components which leads to chargeless and (magnetic) spinless state from a mathematical viewpoint. The only attribute will be (dark) mass for the code. Therefore, the codes in the third row of Table 2 or Table S1 (online) can be regarded as particles/entities which have only (dark) mass attribute (which is different from the mass of matter due to the Higgs field). In this case, all these codes can be useful for discussions related to dark matter particles. As indicated by these codes, dark matter particles may exhibit spin (rotational motion) and moment (linear motion) in either unidirectional or opposite directions. That is to say, dark matter can also have angular and linear momentum. "Monopole" type of dark matter particle is also mathematically possible.

8.4 More permutations of codes and their applications

As we have seen from the above sections, the codes in Table 2, which is the periodic table of properties of the codes of matter, can be used as building blocks to form new electronic and/or spin states in materials. This resembles using the elements in the periodic table of elements to form chemical compounds. The fundamental difference, however, is that the codes can directly guide the formation of new materials/matter with new electronic and/or spin states, while the periodic table of elements yields compounds with little information on physical properties. We now use the same principle to form more combinations of codes in order to predict new electronic or spin properties. One can have more permutations between the two of the four different groups of the 60 codes (Table 2). This will lead to more exotic and interesting features of Q, K, or S states. We only select some typical codes for discussions (Tables S15–S24 online and discussions in Electronic supplementary material).

8.5 Applications in optics

Since the charge neutral codes having both S and K can also be regarded as photons, the codes in the $Q = 0$ raw of Table 2 can be used to discuss various states of photons. We denote as moment or wave vector, the or code represents right-handed or left-handed circularly polarization, and or as linear polarization with 90° phase difference. The code 41 in Table 2 represents a static photon and code 47 in Table 2 is a light or a photon without any polarization. The code 49 or 51 in Table 2 represents right-handed or left-handed circularly polarized photon with opposite K, respectively, while the code 53 or 55 in Table 2 represents linearly polarized photon with the same K. The codes formed by paring the codes in group II with $Q = 0$ of Table 2 is given in Table S25 (online). Most paired codes represent photonic states that have known to us, while some of them show interesting and strange features which inspire us to design new optical systems or devices with exotic photonic states. Here, we discuss a few typical paired codes (Fig. 7) representing known and unknown photonic/light states.

The physical meanings of these codes are straight forward when each code is present using two different media as shown in Fig. 8. Code a means a non-polarized light is polarized in the second medium with right-handed circularity. Code c represents a linear polarization process, while code d or f in Fig. 8 represents a right-handed circularly polarized light which is converted to a linear light. The codes in the second raw of the Fig. 7 can represent the photonic states of reflection at interface

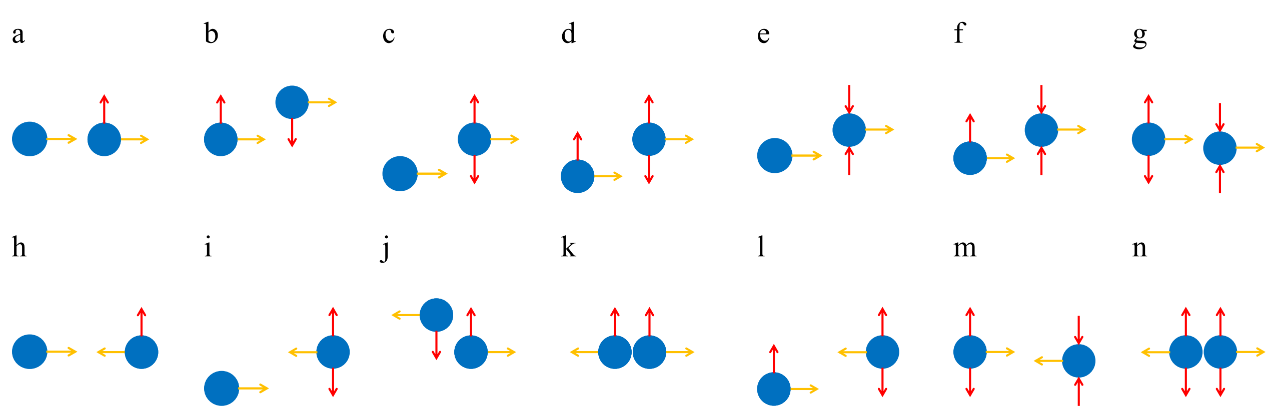


Fig. 7 A few typical codes with the same or opposite K extracted from Table S25 (online)

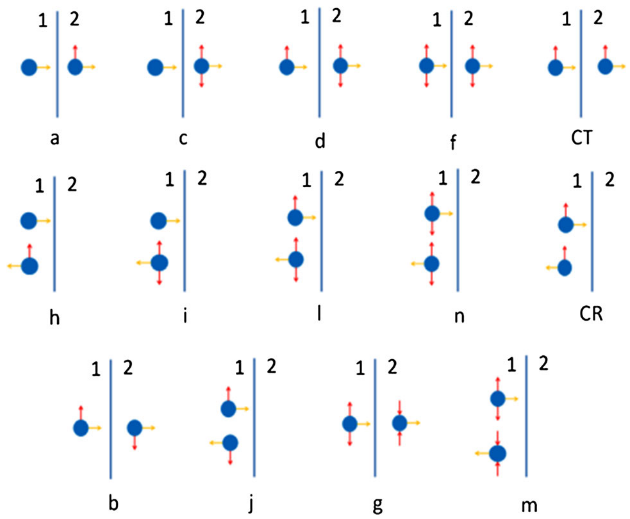


Fig. 8 Photonic states for either transmittance or reflectance in two different media: 1 and 2. The CT and CR mean conventional transmittance and reflectance, respectively. All other letters are the same as indicated in Fig. 7

of two media. Codes h and i in Fig. 8 refer to non-polarized light are converted to circularly or linearly polarized reflected light, respectively. The code k or n represents the polarization of both the incident and reflected light are conserved. It is interesting to note that the codes b or j in Fig. 8 indicates a circular-to-circular polarization conversion (having opposite circular polarization) in the second medium or at the reflection interface. It can also be regarded as photonic states with the time-reversal symmetry which resembles the surface electronic state in electronic topological insulators. The time-reversal symmetry protects the light travels one way only without any reflection at interface of two media, similar to what is seen in topological photonic edge states [20]. The codes g and m represent linear to linear conversion with 90° phase shift or time-reversal symmetry state for linear polarizations. Note that the above discussions only deal with codes formed by two single codes. One can image that new codes having three single code can show more and exotic photonic states for incidence, transmittance, and reflectance of light. The applications in chemistry are shown in Electronic supplementary material for detailed discussions.

9 Ternary and quaternary codes

9.1 Systems by localized codes

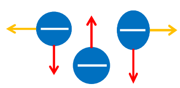
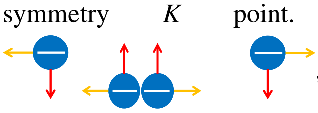
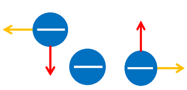
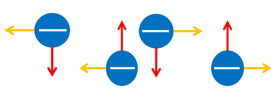
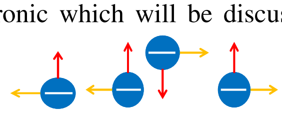
What have been discussed so far are based on pairs of single particles. In analogy to chemical compositions containing more than two elements, such as binary or ternary systems, all the paired codes can be termed "binary codes". The combinations of codes in Table 2 can now be extended to "ternary" and "quaternary" codes with the same criteria for charge balance and spin stability.

The codes for localized particles can produce 14 ternary codes, as shown in Table S26 (online). Note that each code can have different orders for each individual code. These codes represent a dipole coexisting with a charge neutral particle, with or without spin. Using these ternary codes, we can produce materials with the properties of both electric dipoles and spins that are either parallel or antiparallel. Interestingly, in a similar way to the chemical formulas for compounds, we can define a formula for physical properties related to spin and charge, that is, (charge only code)$_x$(spin and charge code)$_y$(charge neutral code)$_z$, where x, y, and z could be integral or fractional numbers, which is the same as what is used for chemical compositions, but with the charge balance criteria for the code property formula. For example, $(\ominus)_2(\oplus)_2(\bullet)_1$ represents two negative, two positive charges, and one neutral particles in a unit cell of property of codes. $(\ominus)_n(\oplus)_n(\overset{\uparrow}{\bullet})$ could mean a diluted magnetic system or a magnetic impurity.

It should be noted that the ternary codes represent codes for a neutral particle coexisting with codes for negative and positive charges. This inspires us to look at single molecular systems or nanosystems having net zero charge, but which can attach charged atoms, such as single molecule C_{60} cages [21] with adsorption of molecules inside or outside the cage and other type of single molecular cages. From this perspective, more new types of such molecular systems can be discovered, such as the codes $\ominus\oplus\overset{\uparrow}{\bullet}$ and $\ominus\overset{\uparrow}{\oplus}\overset{\uparrow}{\bullet}$, referring to magnetic cage attaching an electric dipole molecule and a magnetic molecule, respectively.

Remarkably, both the ternary and the quaternary codes can inspire us to design new multiferroic systems [22] as they feature both spin and dipole moments. It is exciting to note that the new multiferroic systems produced by these codes are remarkably different from the conventional multiferroic systems, which are all long-range ordered, either magnetically or electrically, and structurally. Here, we propose a new type of system, namely, molecular multiferroic or nano-multiferroic systems, as all the codes possess both spin and charge dipoles, but at the molecular level. The proposed molecular multiferroic systems are single molecule based and have both spin and electric dipoles. The junctions built on them could lead to a new type of single or multiple molecule electronics, which can be termed single or multiple molecular multiferroics. One can imagine that the multiferroic single molecules can also be used as building blocks to construct 1D, 2D, or 3D materials with van der Waals interactions between molecules. It can be predicted that the crystals, their spin and electric structures, and their coupling are more sensitive to external disturbance than those seen in all the 2D or 3D multiferroic systems studied so far. This is because any changes in strain, electric, and magnetic fields, or even light radiation can cause the redistribution of charge in the system, which, in turn, greatly changes all three properties. This type of new molecule-based multiferroic system will provide a new platform for novel multiferroics. The molecular-based multiferroic systems are rich in quaternary codes. It is interesting to note that a new class of materials which contains the inert atoms in the periodic table of elements, such as He, Ne, and Ar, could be possible, as indicated by the codes in Tables S26, S27 (online).

9.2 Systems with codes of linear motion and localized codes

There should be many permutations of codes consisting of both localized and free particles, inspiring us searching for systems having exotic electronic and spin states. Here, we only discuss a few typical codes with interesting states (Table S28 online). The ternary code  indicates special electronic states at the Fermi level of a conduction band (Fig. S6a online) which leads to the Van Hove singularity [23], while the code  is represented with a spin-up code with $K = 0$ at a high symmetry K point. A quaternary code , is represented at a higher Fermi level. Both cases in the Fig. S6b (online) are based on a band structure of a Weyl metal. The Fig. S6c (online) shows the representative band structures for  and  codes. Depending on the position of the E_f, the codes for holes have the similar band structures. The multicodes can represent many exotic electronic which will be discussed in future work. The codes  represented band structure is shown in Fig. S6d (online). Note that the dispersion of E–K is linear which corresponds to the band structure of a (N-type) Weyl semimetal with opposite chirality [23, 24].

10 Prospects

The three paramount and ubiquitous attributes Q, S or rotational motion and K are the primary and original codes of matter, and they can be used to produce more codes, which are encoded in all the complicated forms of matter/materials/entities/objects and their properties. The production of codes is the very simple mathematical combination of a very few primary codes, such as −Q, +Q, −K, +K, and −S and +S, but it leads to abundant codes which possess wealthy physical meanings. We have seen that all the existing particles, quasiparticles, and localized or delocalized charge and spin states that have already discovered experimentally, or postulated mathematically or theoretically so far can find their corresponding counterparts represented by the codes of matter. Remarkably, many codes which do not have counterparts in existing forms of matter can represent and predict novel forms of matter or novel electronic, magnetic or spin states as well as new photonic states. Dark matter particles can also be represented by the codes having no charge components. The principles of the codes of matter reveal that the search for new forms of matter will never be exhausted. The prediction of new forms of matter and what they should be, and what mysterious properties they would have in reality are clearly represented by their codes.

With a strong resemblance to the periodic table of elements, which is used to form compounds with a certain composition or a formula, the 60 codes of single entities can be used to form any types of entities with predictable properties as they are based on their Q, S, and K. Furthermore, the codes of matter can not only predict new forms of matter/materials associated with charge and spin and photons or light, but can also find applications in searching for new microscopic and macroscopic systems/objects, which are represented by the charge neutral code, with spin representing self-spinning or rotational motion. It should be pointed out that all the discussions on the codes of matter are based on zero or one spatial dimension. They all can be extended to 2D and 3D to construct forms of matter in reality.

Moreover, the physical meaning that is unlocked for most of the codes in this work is mainly related to the magnetic spin and electric charge. It is certain that there are many other meanings for codes that represent systems in which the spin is self-spinning and charge is absent. Searching for new macroscopic systems based on the principles of the codes of matters, and the experimental and theoretical exploration for the new forms of matter, new quasiparticles, or new electronic and spin states represented by the codes of matter are imminent. The codes of matter should find wide applications in the wettability which is a very active topic in chemistry. In addition, the codes having both moment and spin inspire new fundamental mechanisms that need to be considered for chemical reactions. The codes of matter offer a new alternative simple platform and principle for scientific research that can be added to the existing research methodologies. The table of the 60 codes of matter also provides a new horizon for designing new properties and forming new compounds and materials.

We know that there should be more new materials and new electronic, spin, and photonic states to be discovered, but we do not know what they are. The codes of matter clearly reveal to us how many and what they are and how easily we can recognize what they are. Experimental and theoretical exploration for new forms of matter, new quasiparticles, new electronic and spin states, or new states of photon or properties of light, as well as macroscopic entities with exotic properties represented by the codes of matter, is imminent.

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